

THE EXPLOSION OF GASES.

THE earliest work on the explosion of gases was that of Humphry Davy, who in 1817 published those celebrated experiments on "the propagation of flame through small tubes and orifices" which led him to the construction of the miner's safety-lamp.

More than half a century later Bunsen devised the non-luminous gas burner, observing that unless the flow of the mixture of coal-gas and air exceeded a certain rate the flame became unsteady and passed down the tube. Bunsen believed that this rate represented the velocity with which an explosion would travel in the combustible gases in a closed tube, and he obtained definite values for a number of mixtures by leading the gases through an orifice at the end of a tube, igniting the jet, and determining the minimum speed at which the gases must be forced through the tube to prevent the flame passing back through the opening. The rates of explosion measured in this way were comparatively slow, the fastest observed

being about thirty-seven yards a second.

But in 1881 Berthelot and Vieille discovered that when an explosive mixture is ignited at the end of a long pipe, the velocity of the explosion rapidly increases from its point of origin until it reaches a maximum velocity, which remains constant however long the column of gas may be, and which greatly exceeds the speeds of combustion measured by Bunsen; this discovery was confirmed by the independent investigations of Mallard and Le Chatelier, published at the same time. Berthelot gave the name "l'onde explosive" (detonation-wave) to the flame travelling with its

maximum velocity, thus distinguishing it from the variable progressive combustion which precedes its development. The velocity of the explosion-wave constitutes a physical constant which has a specific value for each inflammable mixture; measurements by Berthelot and H. B. Dixon have shown that it is approximately equal to the velocity of sound in the burning gases at the temperature of the explosion. For a mixture of hydrogen and oxygen in equivalent proportions the velocity is about 3000 yards a second.

Mallard and Le Chatelier succeeded in recording the slow movements of the flame of progressive combustion by photographing the flash on a piece of sensitised paper fixed on a revolving cylinder. They found that when the gases are ignited at the open end of a long tube, the flame travels for some distance with a uniform slow velocity of the order measured by Bunsen; the flame next begins to vibrate, swinging backwards and forwards with oscillations of increasing amplitude; then it either dies down or sometimes the gas detonates. If the gas is fired near

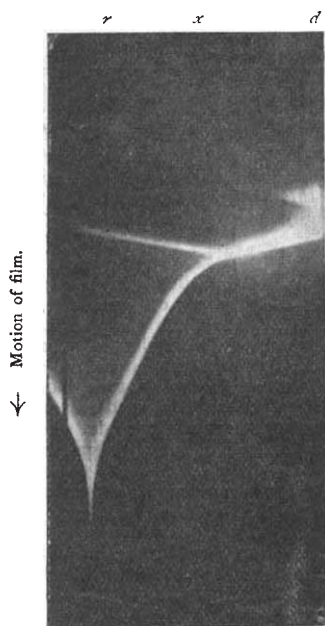
the closed end of the tube, the movement of the flame is uniformly accelerated until the detonation is set up. Le Chatelier's apparatus was not fast enough to analyse the wave of detonation itself.

The apparatus used by Prof. H. B. Dixon consists of a drum carrying a narrow strip of Eastman film, which can be rotated at the rate of 100 metres a second. The explosion tube is fixed horizontally, and the image of the flame is focussed on to the vertically moving film. The photographs show an inclined line of light compounded of the two motions. Fig. 1 is a photograph of the explosion of cyanogen with oxygen. The mixture was fired near the middle of a tube by an electric spark *s*. The flame moves slowly in both directions; to the left it passes out of the field of view, to the right its speed increases until at *x* the detonation-wave is set up. The detonation-wave, moving with constant velocity, is represented by a straight line (*x*, *d*), while the slower movement of the progressive combustion preceding it is shown as a curve (*s*, *x*), the steepness of which diminishes as the motion of the flame accelerates—the speed of the drum being uniform. The duration of the flash was less than 1/100 second. The period before the detonation is distinguished not only by the slow movement of the flame, but also by slow and incomplete combustion and feeble luminosity.

The initiation of the detonation-wave is marked by certain characteristics—(1) a sudden increase in intensity of the flame, accompanied by an instantaneous rise in pressure; it is found that glass tubes are most often fractured at the point where the detonation originates; (2) rapid and complete combustion; (3) the setting up of a strongly luminous backward wave (*x*, *r*)—the so-called "retonation-wave"—which under certain conditions travels as rapidly as the detonation-wave itself. The sudden rise in pressure is due to the increase of chemical action, and this pressure not only produces the forward detonation, but also sends a backward wave of compression into the slowly-burning gases behind it; this compression-wave raises the temperature of the combining gases and increases the luminosity. It should be observed that the light produced by the explosion is chiefly due to particles knocked from the glass and raised to incandescence; the small particles suspended in the burning gases glow by the heat imparted to them by the hotter but invisible gaseous products of combustion.

The detonation-wave is set up only after the flame has run some distance, which depends on the nature of the mixture and on the size of the spark.

Fig. 2 shows the explosion of hydrogen and oxygen in a closed glass tube too short to allow of the detonation being set up. The gas is fired in the middle of the tube, and the flame spreads right and left with faint luminosity. The flame is preceded by an invisible compression-wave which travels with the



s Flame →
FIG. 1.



FIG. 2.

velocity of sound through the unignited gas, and is reflected from the ends of the tube. The flame is checked while these two compression-waves pass through the burning gases, and is then helped forward by the waves moving in the same direction. The movement then becomes unsymmetrical; the flame to the left is checked a second time before it reaches its end of the tube, that to the right reaches the end of the tube and sends back a strong reflection-wave. The wave from the right is of greater intensity and moves more rapidly than that started a little later from the left, and, although the reflections of these waves at first run nearly parallel, the stronger gradually overtakes the weaker and coalesces with it, and the single wave continues to traverse the tube from end to end. As many as one hundred reflections have been counted in an explosion of this kind. Fig. 3 shows in outline the movements of the flame and compression-waves.

The flame in its initial stage is only very feebly luminous, a fact which has led to erroneous beliefs in regard to the mechanism of explosion. Von Oettingen and von Gernet, failing to photograph the flame itself, introduced finely-divided salts into the tube, and obtained brilliant pictures of the explosion showing a series of parallel waves. They believed that the explosion itself was *quite invisible*, the movements shown in the pictures being compression-waves rushing through the burning gases after the explosion

was completed. These parallel waves, following each other in close succession, were supposed to be due to "successive partial explosions" proceeding from the spark, in accordance with Bunsen's theory of discontinuous step-like combustion.

The influence of water vapour on the combustion of hydrogen with oxygen has formed the subject of much recent research. Some years ago Dixon showed that an electric spark would fire ordinary electrolytic gas whether in the dried or moist condition, and that the velocity of detonation was practically unaffected by the presence of aqueous vapour. The experiments of Baker with very pure hydrogen and oxygen have, however, shown that the initiation of the flame is

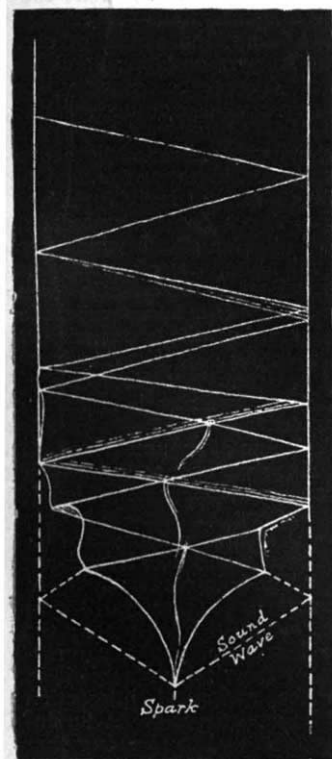


FIG. 3

largely influenced by the purity of the mixture. It might be expected that the initial phase of the explosion (before detonation is set up) would be modified if the interaction of the gases depends on the presence of previously formed water molecules. Dixon and Bradshaw have shown by photographs that this is not the case; the flame, once it has been started by a spark, spreads with the same velocity in the dry as in the moist gases, and undergoes the

same changes in intensity. So far as the development and movements of the flame are concerned, the presence of water-vapour appears to make no difference in the union of hydrogen and oxygen.

In a recent paper Dixon and Bradshaw have shown that the compression-wave which travels in front of the flame in the initial stage of the explosion may, under certain conditions, bring about the spontaneous inflammation of the gases in a region of the tube some distance from the spark.

Fig. 4 shows the explosion of hydrogen and oxygen in a tube one end of which has been drawn off in the blowpipe flame in the manner of a Carius bomb-tube, so that the end has the form of a funnel followed by a short capillary. The explosion is started in the middle of the tube (s); almost simultaneously the gas inflames in the capillary (c). The flames meet midway between the fine dark vertical lines, which



FIG. 4.

are reference marks produced by fastening narrow strips of black paper outside the explosion tube to eclipse the flame as it passes. The broad band is due to the clamp which held the tube in position. The firing of the gas in the capillary is caused by the sudden increase of pressure in the funnel, the heat of compression raising the gases to the temperature of ignition. The wave produced is analogous to the tidal "bore" in a funnel-shaped estuary. L. B.

THE SEVENTH INTERNATIONAL ZOOLOGICAL CONGRESS.

THE meeting of zoologists at Boston was formally convened on Monday, August 19, in the Jordan Hall. Prof. Alexander Agassiz, as president, welcomed the members and delegates, and gave a short but vivid address on the recent progress of oceanographical research, especially in its zoological aspects. He directed attention, for instance, to the extremely interesting facts which he has discovered in regard to the relations of the deep-sea faunas on the two sides of the Isthmus of Panama. In a country where the stranger cannot but be impressed with the amount of public and private money which seems to be placed at the disposal of scientific institutions, it was interesting to hear Prof. Agassiz's complaint that the Government had not taken any steps to publish an account of the treasures of the *Albatross* expedition. It was one of those touches of nature which make the whole world kin.

Vice-presidents were appointed, such as Mr. Bateson (England), Prof. Hubrecht (Holland), Prof. H. F. Osborn (United States), Dr. Watake (Japan); and, on the report of Prof. Blanchard, the Czar Nicolas prize was awarded to Prof. Cuénot, of Paris, for his research on hybrids. Special mention was also made of theses by M. Loisel, of Paris, and M. Standfuss, of Zürich, which did not arrive in